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The Potential for Active Solar Heating in Warehousing and Light Industrial Buildings

A RESEARCH REPORT

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The Utilization and Potential for Active
Solar Heating Systems in Canadian
Warehousing and Light Industrial Buildings

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The Buildings Energy Technology Transfer Program (BETT) of ENR has been created to assist building owners, users and practitioners active in the design, construction and operation of buildings in identifying technical obstacles to energy conservation. Through a nationwide network of research agencies and private sector consultants, BETT carries out research and development projects and provides the audiences mentioned above with technical reports, how-to manuals, training manuals, audio-visual aids and data bases to help them overcome these obstacles.

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ABSTRACT

In this report the use and the potential for use of active solar heating systems in the warehouse and light industrial building category is assessed. Various service and process related heating loads and the nature and cost of the likely active solar heating system are considered.

Active solar heating systems are suited to supplying low-temperature water heating. The solar system would be comprised of flat plate solar collectors with or without a thermal storage unit. Water-based space heating is not as good an application for solar heating as low-temperature process or service hot water.

There is some potential for air-based solar heating systems to supply process and ventilation air heating loads. To date, air-based solar heating systems have not been widely used in warehouse or light industrial buildings.

Space heating of warehouses using thermosyphoning air panels is recommended as one of the best solar heating applications. Installations are, however, required to determine the full potential of these systems using installed costs and actual performance data.

RÉSUMÉ

Dans le présent rapport sont évalués les applications et le potentiel d'utilisation des systèmes de chauffage solaires actifs dans les bâtiments d'entreposage et les bâtiments industriels à structure légère. On y prend en considération les besoins en chauffage propres à diverses fins résiduelles et industrielles ainsi que la nature et le coût des systèmes de chauffage solaire actifs qui conviendraient.

Les systèmes de chauffage solaires actifs conviennent à l'alimentation en eau chaude de capteurs plans assortis ou non d'une unité de stockage thermique. Le chauffage des locaux à l'eau chaude n'est toutefois pas une application aussi avantageuse qu'est celle du chauffage, à des températures modérées, des eaux résiduelles ou d'usage industriel.

Les systèmes de chauffage solaires par circulation d'air qui servent à fournir une charge calorifique pour usage industriel ou fins de ventilation ont un certain potentiel d'utilisation. Jusqu'à maintenant, les systèmes de chauffage solaires par circulation d'air n'ont pas connu un usage répandu dans l'un ou l'autre des types de bâtiments.

Le chauffage des entrepôts à l'aide de panneaux à circulation d'air par thermosiphon est recommandé, c'est l'une des meilleures applications du chauffage solaire. Avant de procéder à l'installation, il faut toutefois déterminer quel est le potentiel ultime de ces systèmes en prenant en considération les coûts d'utilisation et des données de rendement concrètes.

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The Buildings Energy Technology Transfer Program (BETT) was initiated by the Department of Energy, Mines and Resources (EMR) of the Government of Canada in late 1981. The principal objectives of this program are:

- to identify the potential for energy conservation in both new and existing building
- to determine R, D and D requirements and their priority in order to exploit this potential
- to perform and/or expedite the necessary R, D and D
- To effectively transfer the necessary technology to the appropriate individuals, groups or agencies
- to provide technological support to EMR in the development of policy and programs

The Building Engineering Group (BEG) was selected* by EMR to develop and execute a comprehensive R, D and D program for energy conservation in the warehousing and light industrial building sector. BEG is a semi-autonomous, non-profit agency associated, through the Waterloo Research Institute (WRI), with the University of Waterloo. This multi-disciplinary group attempts to provide a comprehensive range of R and D services to the building industry.

The warehouse and light industrial building sector is particularly important because:

- the square footage of building space encompassed by this category is second only to that of the residential building category
- to date very little R and D, energy-related or otherwise, has been directed towards this building category
- the nature of these buildings, both new and existing, makes them particularly amenable to some degree of energy conservation

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September 20, 1981

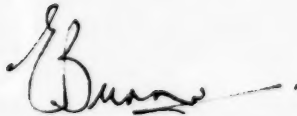
In the initial phase of the R, D and D program developed by BEG, the priorities were to:

- establish a statistical profile of the building category
- develop a comprehensive review of the current state-of-practice
- initiate the development of a portfolio of representative case histories

Ten related studies are being undertaken in this initial phase, Seven of these studies provide either supporting documentation or input for a comprehensive state-of-practice report.

It was realized that an assessment of the relevance of active solar systems was needed. This report entitled "The Potential for Active Solar Heating in Warehousing and Light Industrial Buildings" was prepared by Stephen Carpenter of Enermodal Engineering Limited. Although this report has been distributed as a stand-alone document it should be read in conjunction with the other six reports that contribute to the state-of-practice review.

This report is an early product of what is intended to be a concerted multi-year program of research, development, demonstration, dissemination and evaluation. Feedback with regard to the report or related issues is welcomed and should be directed to the undersigned.



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Warehousing and light industrial buildings have heating loads which can be described as neither process nor people-dependent. The main heating requirement for warehouses is space heating. In many warehouses space heating is needed only to keep the building interior above freezing. Light industrial buildings, although dominated by space heating requirements, have many process water and air and service water heating loads. For example, soft drink manufacturers have a large demand for hot water for bottle washing and can warming. Vehicle storage depots often require service hot water for washing of trucks and buses.

Active solar heating is receiving considerable attention and support from many government departments and agencies, so that it may supply a sizable portion of Canada's energy demand. These groups include The National Research Council of Canada, Public Works Canada, Energy, Mines and Resources Canada, Ontario Ministry of Energy and the Institute of Man and Resources (P.E.I.) among others. In addition to public sector interest, there are over fifteen companies in Canada manufacturing solar heating systems and many more involved in designing, installing and selling these systems.

The question arises as to whether warehousing and light industrial heating loads can be met by solar heating equipment. This report examines the utilization and potential of active solar heating systems to meet the major warehousing and light industrial heating loads. The loads examined are:

- low-temperature process water heating,
- high-temperature process water heating
- service hot water heating,
- water-based space heating,
- process or ventilation air heating,
- air based space heating,

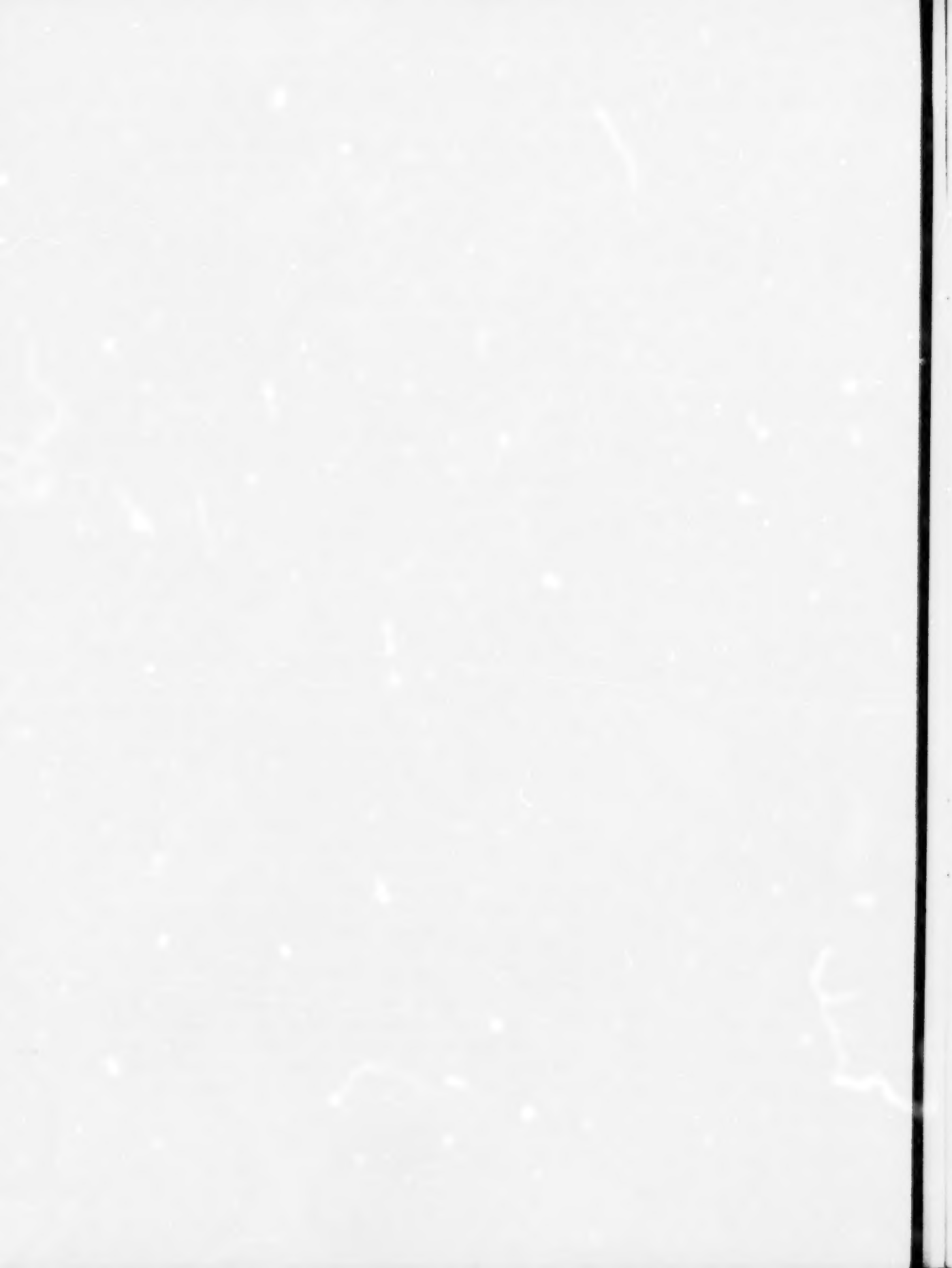
Air-conditioning/refrigeration is considered an inappropriate application for solar energy in Canada and is not examined. Although there are many possible ways that solar energy can supply part of these loads, only commercially available methods are considered. Long-range solar energy conversion techniques, such as photovoltaics and solar power towers, are not examined. The Canadian solar manufacturing industry is reviewed and available products are discussed. The present and future economics of solar heating systems are discussed, and the research and development

requirements for the solar industry to meet warehousing and light industrial demands are outlined.

Most of the research, development and commercialization of solar heating in Canada has focused on heating demands for temperatures below 65°C. Almost all Canadian solar equipment manufacturers produce a glazed flat plate solar collector for efficient heating of air or water/antifreeze for this application. For temperatures between 65 and 100°C, an evacuated tube solar collector is usually used. For temperatures above 100°C, a sun tracking or concentrating collector is required. It is difficult to operate this type of collector in the Canadian climate because of snow loads and icing of tracking motors. For outdoor swimming pools or applications where water temperatures are slightly above ambient temperature an unglazed, plastic, absorber collector can be used. Several manufacturers have a glazed swimming pool collector which can supply water at temperatures up to 30°C for 5 months of the year.

Solar collectors are combined with a thermal storage unit, heat exchangers, piping, pumps and controls to form a solar heating system. Almost exclusively these systems are designed to be a supplementary heating source. The conventional heating system would meet heating needs on cloudy, cold days. Although early installations had mechanical problems, systems installed today are relatively maintenance free. Maintenance requirements are replacement of glycol every three years and motors every ten years. Systems are designed to last a minimum of twenty years with no major equipment replacement. Vandalism has not been a problem.

Hollands and Orgill (1) in a 1977 study of the solar heating potential in Canada calculated the performance of solar heating systems in nine cities across Canada. They determined that solar heating systems performed in a similar fashion for each of the nine cities, with the locations that benefited from high solar radiation suffering from low ambient temperatures or vice versa. Thus, it is not necessary to make regional distinctions when discussing the thermal potential of solar heating in Canada. Of much greater significance in terms of solar heating potential are the regional variations in fuel costs. Thus, the high cost of energy in the Maritimes makes solar heating more attractive than in Alberta.



2.1 Low-Temperature Process Water (below 100°C)

Heating of low temperature process water is a good application for solar heating systems. Because the heating load is constant on a daily and seasonal basis, the solar heating system can operate continuously, as opposed to solar space heating systems where the system lies idle for the summer months. Also, the lower the required process water temperature, the more efficient the collector operation. Flat plate solar collectors can operate efficiently up to 65°C. Evacuated tube collectors are effective in supplying water at temperatures up to 100°C. For temperatures above 100°C a concentrating collector is required; this is discussed in Section 2.2.

There are two types of solar heating systems that are used for low temperature process water.

The most common system uses an array of flat plate solar collectors connected to a thermal storage tank. The collectors heat the water in the tank and, as needed, the water is drawn from the tank, heated by an auxiliary heating unit to the desired temperature, and delivered to the load. If the process load is for a five day period, i.e. no usage on the weekend, the storage tank must be larger than for a seven day load in order to store the solar heat for two days. Typically, this type of system can deliver over 60% of the heating requirement provided the process temperature is below 65°C.

The second system is the zero storage solar heating system. In this system the storage tank and associated piping, valves and controls are not required. The elimination of the storage tank typically results in a 20% system cost reduction and virtually eliminates the solar heating system floor space requirements. There is, however, a thermal performance penalty, the magnitude of which depends on the process water demand schedule. The ideal demand for a zero-storage system is seven days a week with most of the load in the central hours of the day. Chorley and Bissett Limited examined the performance of zero-storage systems with this load profile and found that for solar contributions of up to 25% there is little loss in performance (2). The performance drops off rapidly beyond this value: when the solar contribution constitutes 35%, the loss in performance equals the capital cost savings.

For a five-day demand profile, the performance penalty is approximately equal to the storage tank cost savings.

In a report on industrial solar applications, Giffels Associates Limited identified many low-temperature process water heating requirements (3). Although some of the processes are for building types outside the type examined in this study, many of the processes are applicable. They estimated that solar heating could potentially supply 600000 GJ of low-temperature process heat per year in Canada.

The major consumers of this energy are:

- poultry processors (scalding)
- soft drink manufacturers (bottle and can warming)
- breweries (pasteurizing)

The minor consumers of low-temperature process heat include:

- fish hatcheries
- film processors
- food processors (wash-up/rinsing).

All of the above processes require water with an end use temperature of less than 65°C.

It should be noted that many higher temperature processes must heat water from the city mains temperature to the process temperature. Thus a low temperature (flat plate) solar collector can be used for the preheating of the water. A high temperature solar collector (such as the evacuated tube) or a conventional heating system could then be used to raise the water temperature up to the process temperature.

Major consumers of 65 to 100°C process water are:

- meat processors (slaughtering)
- soft drink manufacturers (bottle washing)
- breweries (bottle washing)
- metal coating industries (metal cleaning)
- concrete products manufacturers (curing)
- fibre and yarn manufacturers (dyeing)

This group has a solar heating potential demand of 3300000 GJ per year in Canada. Of this value only

60 to 70% could be met by flat plate collectors. Thus the total solar heating potential for process heat below 65°C is approximately 2.7 million GJ per year in Canada. This represents the installation of approximately 3/4 of a million flat plate solar collectors (based on a system performance of 1.8 GJ/(m² · a) and a collector area of 2 square metres).

In a report prepared for the National Research Council, Hickling-Partners Inc. identified the five most promising industries for solar heating (4). They are breweries, leather tanneries, meat processing, dairy products and soft drink manufacturers. All of these industries fall into the light industry building category. Their criteria for selection were that the industries be located in Quebec and Eastern Canada (oil dependence) and use large volumes of low temperature water.

Most of the systems that could be installed for the processes described above would be conventional solar water heating systems (with a storage tank). There are, however, some processes that require hot water six or seven days a week that could effectively use a zero-storage system, e.g., bakeries.

Table 1 gives a list of the solar process water heating systems installed across Canada. This list was prepared through consultation with solar manufacturers and government officials and a review of the literature; it contains most of the current installations. All of these systems were installed with government financial assistance.

2.2 High-Temperature Process Water/Steam Heating (above 100°C)

For process water temperatures above 100°C, flat plate and evacuated tube solar collectors are not suitable as their efficiency is very low.

Temperatures of over 100°C require trough or dish-type mirrors to concentrate solar radiation onto a smaller receiver. At present there is no Canadian-made collector of this type (see Sections 4.2 and 4.3), although several studies are underway to develop high-temperature solar collectors.

TABLE 1: Solar Low-Temperature Process Water Heating Installations

<u>User</u>	<u>Location</u>	<u>Process</u>	<u>Major Funding Source</u>
Huron Steel Products	Windsor, Ontario	Metal Cleaning	ONT
Christie Brown and Co.	Toronto, Ontario	Food Preparation	ONT
Medallion Film Laboratories	Toronto, Ontario	Film Processing	ONT
Maedel's Beverages	Windsor, Ontario	Bottle Washing	ONT
Scherer Gelatin Capsules Ltd.	Windsor, Ontario	Container Washing	ONT
Fresh Water Fish Processing Plant	Manitoba	Fish Processing	PUSH
Cardigan Fish Hatchery	Nova Scotia	Fish Hatchery Tanks	PUSH
Manitoba Fish Hatchery	Gunton, Manitoba	Fish Hatchery Tanks	PUSH
Wolverton Fish Hatchery	Centreville, N.B.	Fish Hatchery Tanks	PUSH
Etco Photo	Montreal, Quebec	Film Processing	EMR
Gaza Products Inc.	Montreal, Quebec	Food Processing	NRC
Globe and Mail	Toronto, Ontario	Photographic Plate Prod.	NRC
Work Wear Corp.	Brantford, Ontario	Clothing Production	NRC
Mountain Spring Beverages	Edmonton, Alberta	Bottle Washing (evacuated tube)	NRC

NRC - National Research Council

PUSH - PUSH Program Public Works Canada

ONT - Ontario Commercial/Industrial Solar Demonstration Program

EMR - Energy, Mines and Resources Canada

The design of a trough or dish type mirror (reflector) for the Canadian climate is complicated by snow and ice loads and the large differential thermal expansion. These factors necessitate a heavier and sturdier structure than required in warmer climates. Until a concentrating collector suitable for the Canadian climate can be produced at a reasonable cost, processes requiring temperatures above 100°C are not compatible with solar heating. Thus, concentrating collectors are not suitable for warehousing and light industrial buildings.

2.3 Service Hot Water

Many light industries require service hot water, defined as hot water used for cleaning and washing on a variable basis as opposed to a fixed schedule. Solar heating systems in these applications generally use a thermal storage tank. Because of the low delivery temperature of the water (usually 50°C), the solar heating system typically can meet over 60% of the heating load.

The suitability of solar heating to meet this demand depends largely on the frequency of the water draws. Solar heating is well suited to the application where there is a relatively constant water draw each day. There are, however, many industries where service hot water may be used only once a week or where wash sinks and showers have been installed but are rarely used. This type of load requires a large solar storage tank and as a result much of the solar heat is lost to the environment and not delivered to the load.

Industrial operations that use a large amount of service hot water include:

- washing of trucks, buses etc. in vehicle maintenance/storage depots
- food preparation and wash up in industrial cafeterias
- personnel showering at shift end in industrial showers
- washing of work clothes in industrial laundries.

It is difficult to get an estimate of the amount of energy consumed across Canada in service hot water heating because this energy demand is generally a small part of the total building energy demand.

For some industries, however, service hot water consumption can be significant. Hospitals often have their own industrial laundries which require large volumes of wash water. The Mohawk laundry facility in Hamilton is being retrofitted with the largest solar heating system in Canada. The system will save the equivalent of 25000 barrels of oil over the system lifetime (5).

In a report prepared for the Public Works Canada PUSH program, Middleton Associates recommended that car and truck washing is the best application for solar heating (6). Other sectors of interest they identified are laundry and textile. Their criteria for selection were that the building use large volumes of low temperature water and be highly visible to the general public.

As complete a list as possible of solar service hot water systems in Canada is presented in Table 2. Again, the majority of these systems were installed with government financial assistance.

2.4 Water-based Space Heating

Water-based space heating is not as suitable an application for solar heating as process or service hot water heating. The solar space heating system has basically the same components as the process or service water heating with the disadvantage of no heat demand during the summer months. Several solar heating systems have been constructed with a storage system capable of storing summer solar heat until the winter. These systems have been plagued by large thermal heat losses from storage (7), resulting in much of the summer solar heat being lost to the ground before winter.

An additional disadvantage of water-based space heating is the high water temperature required by the radiators (typically over 70°C). An air-to-water heat exchanger can be used to supply solar heat for forced air distribution systems. This type of system is generally more expensive than an air-based solar space heating system (see Section 3.3).

Because of these disadvantages, liquid-based solar

TABLE 2: Solar Service Hot Water Heating Installations

<u>User</u>	<u>Location</u>	<u>Process</u>	<u>Major Funding Source</u>
Air Canada	Doval, Quebec	Airplane Washing	PUSH
DeHavilland Aircraft	Toronto, Ontario	Airplane Washing	PUSH
Canadian National	Taschereau, Quebec	Rail Car Washing	PUSH
Polysar Limited	Sarnia, Ontario	Showers	ONT
Mohawk Laundry	Hamilton, Ontario	Clothes Washing	MOE
Imperial Oil Limited	Toronto, Ontario	Truck Washing	User
Provo Cartage	Montreal, Quebec	Truck Washing	NRC
Colgate-Palmolive	Toronto, Ontario	Washing Up	User

NRC - National Research Council

PUSH - PUSH Program Public Works Canada

ONT - Ontario Commercial/Industrial Solar Demonstration Program

MOE - Ontario Ministry of Energy

space heating systems, although technically feasible, are not as economically attractive as other applications and, thus, are not recommended for warehousing and light industrial buildings.

3.1 Process or Ventilation Air Heating

For many industries, process or ventilation air heating is an excellent application for solar heating systems. In many industrial processes large volumes of air must be heated from the ambient temperature to the process temperature. The process temperature can be above the useful range of air-based solar collectors; nevertheless, the collectors can be used effectively to preheat the air.

Although the heating of process air is a good solar heating application, heat recovery equipment is often used to reduce energy consumption. Heat recovery equipment has, however, several notable limitations. The equipment suffers from frost build-up in sub-freezing conditions and fouling from grease and contaminants. It requires modifications if the exhaust air contains corrosive chemicals. The installation of this equipment can be expensive in retrofit situations if return ducting has to be added. The choice of heat recovery or solar heating equipment depends on many building-specific factors, and in some instances solar heating is an appropriate alternative.

As was the case with process water heating loads, there are two possible solar heating systems for preheating process air. One system would consist of air-based solar collectors taking air from the outdoors and feeding it directly to the load or, when there is no demand, to a thermal storage unit. The thermal storage unit is generally a container filled with small rocks. When solar heat is not available at the collectors and there is a demand, air flows through the storage unit to the load. The other system is a zero storage system where the air flows through the collectors directly to the load continuously. If there is no load, the system does not operate. For many buildings the best place to locate the collectors is on a vertical south wall, thereby eliminating the need for support racks and, in many instances, the collector back insulation. Although mounting the collectors vertically reduces the available solar radiation, the material and labour cost savings more than compensate.

Solar process air systems with a storage unit can deliver over 60% of the heating load provided the process temperature is low. Morton and Carpenter

examined solar preheating of ambient air without a storage unit (8). They determined that these systems can have high performance provided the solar contribution is kept low. A maximum solar contribution of 35% was recommended.

There are a large number of industries that use process air. The major consumers of energy for process drying include:

- food processors (food drying)
- breweries/soft drink manufacturers (bottle drying)
- yarn and cloth mills (fabric drying)
- motor vehicle manufacturers (paint drying)
- metal stampers and fabricators
- pulp and paper industries (paper drying)
- chemical producers

Giffels Associates (3) have estimated that solar heating of process air could supply 6.3 million GJ of energy across Canada per year. This is almost three times the amount of energy that solar heating could supply for low temperature process water. Such an amount represents the installation of over two million air-based flat plate collectors. Although most of this energy is used by heavy industrial processes, food and bottle drying is relevant to this study.

Despite the large potential, very few of these systems have been installed. Three installations using this type of system are a carpet drying operation in Ottawa, ventilation air for a vehicle maintenance garage in Toronto, and a concrete block curing operation in Kingston. There are three reasons for the lack of demand for solar process air heating installations (aside from economic considerations, which will be discussed later). First, only three Canadian solar manufacturers are marketing an air-based solar collector. Second, the major purchaser of solar equipment, the federal government through the PUSH program, has very few buildings that require heating of process air. Third, there is a lack of awareness on the part of industry of the potential for this type of system.

3.2 Air-Based Space Heating

There is a large potential for air-based solar heating

systems to meet the space heating demands of warehousing and light industrial buildings. Forced air heating systems can heat buildings at temperatures below those required by hot water radiator systems. Air-based systems, however, have the same disadvantages as liquid space heating systems: no heat demand during the summer months, thereby reducing their effectiveness.

The standard air-based solar space heating system consists of air-based collectors, a rock bed thermal storage unit and connecting ductwork. Although air-based collectors use less expensive materials than liquid-based collectors, experience to date has shown that their installed cost is not less (9). In many cases the cost of installing ductwork exceeds the cost of installing piping for liquid systems. Thus, conventional air-based solar space heating systems do not appear to be one of the better applications for warehousing and light industrial buildings.

An alternative to conventional solar space heating systems is to use thermosyphon air panels (TAP) and no thermal storage unit. In this type of system, inexpensive air-based collectors are attached to the south wall of a building. Air inlet and outlet ports are cut in the wall at the bottom and top of the collector. When the collector air becomes warm it rises and is forced into the building. No thermal storage unit is used. In some cases a small fan is used to assist the circulation of the air.

The system described above is best suited to supply a low solar contribution to a building that can accommodate large indoor temperature fluctuations. A warehouse is an excellent application for a thermosyphon air panel system. The large thermal mass of the warehouse contents will help to minimize the building temperature swing. In many warehouse applications the conventional heating system could be eliminated, with the solar heating system supplying heat when available to increase the comfort for the workers. It is difficult at this time to estimate the number of warehouses that could accommodate large temperature swings without damaging the stored contents. It is likely, however, that there are many warehouses that could be economically fitted with a TAP system as a supplementary heating system.

To date very few TAP systems have been installed in Canada, generally for the same reasons as given in Section 3.1.

Table 3 gives a list of air-based solar space heating systems installed on warehouse and light industrial buildings.

TABLE 3: Solar Air-Based Space Heating Installations for Warehousing and Light Industrial Buildings

<u>User</u>	<u>Location</u>	<u>Type</u>	<u>Major Funding Source</u>
New Brunswick Electric Power Commission Warehouse	Bathurst, N.B.	Trombe Wall	User
Dept. of National Defence Airplane Hangers	Toronto, Ontario	Direct Air Heating	PUSH
Dominion Envelope of Canada Warehouse	Toronto, Ontario	Direct Air Heating	User
Bata Shoes Ltd.	Picton, Ontario	Space Heating	User
Metrus Industrial Park	Concord, Ontario	Space Heating	ONT

PUSH - PUSH Program, Public Works Canada

ONT - Ontario Commercial/Industrial Solar Demonstration Program

4.1 The Companies

An examination of the potential of active solar heating must include an analysis of the ability of the solar manufacturers to supply the necessary equipment. Peat, Marwick and Partners prepared a report for the Canadian Solar Industries Association on the solar industry's activities in 1980 (9). The major conclusions of their study follow.

In April 1981 15 Canadian companies were active in solar collector manufacturing, with the majority (11) located in Ontario. Total flat plate and evacuated tube collector sales for 1980 were 9230 square metres, a 38% increase over 1979 sales. If this increase continued for 1981, total sales would be 12740 square metres or 6800 collectors. The above figures do not include swimming pool collector sales because they are not of interest to the building type studied. It should be noted that solar collector manufacturers are predicting a rate of growth greater than 38%. In 1980 manufacturers were operating at 15-20% of total production capacity. Thus, in 1980 manufacturers could have produced 52700 square metres of collectors.

The 1980 purchase of non-swimming pool solar collectors was dominated by government. The federal government (in particular the Public Works Canada PUSH program) accounted for 51% of the sales, with provincial and municipal governments accounting for an additional 16%. Corporations, which would include warehousing and light industrial buildings, accounted for 22% of collector sales. It is not known how much of the corporate sales are attributable to government subsidies. Corporations, however, represent a much larger share of the market than private individuals or institutions at 3% and 1% respectively.

In 1980 there were 323 dealers in solar collectors across Canada, with over 75% located in Ontario and Quebec. The Atlantic Provinces, where energy prices are the highest, have only 6% of the dealers. Despite this large number, dealers accounted for only 3% of collector sales. It would appear there are many dealers who are dealers in name only and who do not actively market the products.

The solar industry has not been profitable. On

average, each solar manufacturer lost almost \$900,000 in 1979 and \$500,000 in 1980. This represents a 37.3% (1979) and 7.6% (1980) loss to sales ratio. A major reason for this loss was low production levels which meant that manufacturing equipment lay idle for most of the time. It would appear that there are too many solar manufacturers for present market levels. Some manufacturers, however, are financially successful. Petro-Sun Inc., the largest Canadian solar equipment manufacturer, reported a 1980-81 profit of \$500,000 on annual sales of \$2.4 million.

4.2 Solar Products

The Canadian Solar Industries Association lists fifteen liquid-based flat plate collectors, three air-based flat plate collectors and one evacuated tube collector (as of February 1982) as approved for the Public Works PUSH program. To be listed, a solar collector must meet two criteria: a minimum of 51% of direct costs must originate in Canada, and the thermal performance must be determined by an independent testing laboratory according to ASHRAE 93-77 standards. There are other products on the market; however, they do not meet the above criteria, or the manufacturers are not interested in being PUSH-approved.

Of the fifteen liquid-based solar collectors, eleven are of conventional tube and fin, single-glazed design. These collectors have approximately the same thermal performance properties and applications. Two others use teflon inner glazings to reduce top heat loss (Amherst 100 and Solcan 2003). The Solartronics SP2000 collector uses a plastic absorber (Noryl) covered with a polycarbonate glazing and no back insulation. This collector is specifically designed for swimming pools and low-temperature process water (under 35°C). The Nortec TD1000, although of tube and fin, single-glass cover design, uses a single tube inside a tube header at the top of the collector. The inner tube carries the fluid to be heated; the outer tube and vertical risers contain freon. The freon transfers solar heat from the absorber plate to the header by a boiling/condensing action. The collector has the advantage of only two piping connections per panel as opposed to four in most collectors, thereby significantly reducing piping costs. A further advantage is that the collector

can handle highly corrosive fluids such as swimming pool water, sea water and many industrial fluids. This collector appears to have technical advantages over other liquid-based solar collectors in industrial applications.

The three air-based solar collectors are more varied in their design than their liquid-based counterparts. The Amherst 200 collector uses a Tedler outer glazing, Teflon inner glazing, a fibre matrix absorber (similar to a furnace filter) and back insulation. The collector has good thermal properties at low fluid to ambient temperature differences, but efficiency drops off at higher temperature differences. The Solartech Solair collector uses a curved polycarbonate glazing, curved steel absorber, and back insulation. The collector is site fabricated onto vertical or sloped surfaces. The collector cannot be rack mounted. The Watershed air collector has an optical section consisting of a low iron glass cover and steel absorber. Options include a Teflon convection suppressant (honeycomb) and back insulation box. This collector is extremely versatile. The optical section can be mounted directly on a vertical wall for low-temperature ventilation and process air applications. High-temperature application can be accommodated by using the honeycomb and back insulation.

At present there is only one evacuated tube solar collector that is PUSH-approved, the Solartech ETC Module. Amherst Renewable Energies Limited has an evacuated tube collector using tubes made by Phillips; however, this product is not yet PUSH approved. The Solartech ETC module uses tubes manufactured by Owens-Illinois supported in a frame manufactured by Solartech. The collector can only use de-ionized water and must be drained at night to a holding tank to prevent freezing. The Solartech ETC Module is capable of efficiently producing outlet temperatures of up to 115°C. This is the only PUSH-approved collector capable of meeting the light industrial high temperature water loads described in Section 2.1.

4.3 Current Solar Product Development

The National Research Council of Canada is funding research into solar products many of which could supply the energy requirements of warehousing and light

industrial buildings. The product receiving the most attention and funding is the evacuated liquid-based solar collector proposed by Canadian Sun Systems. This collector consists of a metal container box with a flat glass sheet covering a series of parabolic troughs with the absorber tube at the focal point. The air space is evacuated to minimize heat loss. This collector represents a new approach to the generation of high temperatures using solar energy. Because of the many technical problems to be overcome, this collector is not scheduled for production until 1987.

The National Research Council is funding several other groups to study and develop high temperature solar collectors. They include Watershed Energy Systems Limited (Etobicoke, Ontario), Andrew Antenna Company Limited (Whitby, Ontario), Ottawa Solartronics Limited (Ottawa, Ontario), Davis Engineering Limited (Ottawa, Ontario) and Osecor Limited (Manotick, Ontario). Although some of these products may not reach commercialization, the ones that do will fill the void of medium and high-temperature Canadian solar collectors.

In the area of air-based collectors, Guy Blain and Associates of Montreal with the assistance of Brace Research Institute are developing a "Solar Wall" (TAP) collector for industrial and warehousing space heating. The collector is a corrugated steel absorber and FRP glazing mounted directly on the building wall. Early economic analysis shows that the system has a payback period of between five and ten years depending on the assumptions used.

In an area unrelated to water and air based heating loads, the University of British Columbia and Vortek Industries Limited are developing a solar concentrator and light pipe. The collector would concentrate the sun rays into the light pipe. Because of total internal reflections, the light would remain inside the pipe until an opening is reached. The system would be used for transmitting light from the building roof to the building interior, thereby reducing the amount of electrical energy required for operating lights. Although this system has the greatest potential in office buildings, the first demonstration project is being installed on a chemical warehouse in Vancouver. This system could have potential in reducing electrical lighting consumption in warehousing and light industrial buildings.

5.1 Present Economics

Although there are many solar heating installations across Canada, there are few systems that are representative of the present cost of solar heating. This is in large part due to the many solar installations of the Public Works PUSH Program. This program, in trying to create a strong market for solar products, has "force fit" many solar installations onto government buildings. PUSH program officials admit that the prices they are paying for systems are higher than the private sector prices (10). There are, however, two other government-assisted programs which offer fairly representative solar heating system prices: Prince Edward Island's Institute of Man and Resources Solar Domestic Hot Water Program and Ontario's Commercial/Industrial Solar Demonstration Program.

The Institute of Man and Resources (P.E.I.) purchased 20 solar domestic hot water systems for residences across the province. The supplier and installer of the systems was Solarsystems Ltd. of Vancouver, British Columbia. Despite the fact that the systems had to be shipped across the country and installed in small towns across the province, the total installed system price was \$3150.00 per system or \$715.00 per square metre of collector. At Prince Edward Island electricity rates, these systems have a simple payback of approximately 15 years.

The Ontario Commercial/Industrial Solar Demonstration Program installed 30 solar heating systems in 1981. Projects had to meet two economic criteria: the installed cost had to be less than \$770/m² of collector, and the cost divided by the first year energy savings had to be less than \$620/GJ. These criteria forced manufacturers to locate cost-effective installations. The majority of the installations were under \$600/m² of collector (and \$500/GJ), with some installations as low as \$365/m² (and \$300/GJ). The economic payback on these systems is difficult to generalize because of the different fuels displaced. With oil and electricity costing approximately \$12/GJ in Ontario, systems displacing this fuel would have a simple payback of under 25 years. The discounted payback of these systems (i.e., including the high inflation rate of oil prices) would be under 20 years. Although these payback periods are still long, the Ontario program will be tightening the economic

criteria in each of the remaining three years, thus improving the cost-effectiveness of the systems. The economic criteria for 1982 are \$700/m² of collector and \$500/GJ.

The sample of solar heating system installations on warehousing and light industrial buildings is not large. In the first year, the Ontario program had only nine installations applicable to the building types under study. This small sample size does not allow a definitive statement to be made on the cost of solar installations for warehousing and light industrial buildings. The data collected in the second through fourth years of the Ontario program should provide a more definite answer.

Despite the lack of data for the building types under study, several generalizations can be made of the cost of solar heating systems. The average retail price of flat plate solar collectors is between \$150 and \$200 per square metre. The cost of the collectors, however, represents only 30% of the total system cost. Other major costs include storage unit (10%), collector support rack and installation (20%), piping, heat exchangers and insulation (25%) and design/commissioning (10%). These percentages show that it is difficult to make large cost savings by reducing the cost of a single component of the solar system. Significant reductions in the cost of the total system require reductions in the cost of components of the system.

5.2 Future Economics

The thermal efficiency of flat plate solar collectors is not likely to increase beyond the present level. Although collectors are being developed to meet industrial heating loads above 100°C, these collectors will not produce significantly more energy per square metre than a flat plate collector; rather, they simply produce heat at a higher temperature. Thus the economics of solar heating will not change as a result of thermal efficiency improvements. Some of the proposed high temperature collectors will use less material than conventional flat plate collectors. As such, it may be possible that these collectors will be less expensive than flat plate collectors.

To determine if the cost of solar heating equipment is going to decrease, each component must be examined separately. A key to the future price trend of solar collectors is contained in the report prepared by Peat, Marwick and Partners. As discussed in Section 4.1, solar manufacturers were operating at 15-20% capacity in 1980. It has been estimated that this value may now be 35% (11). Solar manufacturers have to cover their fixed overheads from these sales. If they were operating at nearly full capacity, the markup on the product could be reduced. This would indicate that a price reduction is expected as future sales increase. A contrary indicator is the fact that the average collector manufacturer lost almost 0.5 million dollars in 1980. Manufacturers are likely to retain the economic benefit of larger sales volumes. Thus, despite the likelihood of increased sales, the price of solar collectors will probably increase at the rate of inflation or, at best, stay constant. It is unlikely that the price of solar collectors will significantly decrease in the near future.

The component of a solar heating system that is most likely to decrease in cost is the supply and installation of the piping. Because of the unfamiliarity of plumbing contractors with solar systems, installation fees have been high. The installation and insulation of exterior pipe work is generally more expensive than interior pipe work. Steps being taken to overcome these problems are solar installers' courses offered by C.S.A.I., collectors that require less piping (e.g., Nortec TD1000), and the development of pre-insulated piping. It is expected that these steps will result in a slow but steady decrease in piping costs.

Collector support racks are needed to hold the collectors at the proper angle whenever they are mounted on a flat roof. To date, the cost of these racks has been high because of overdesign and the long spans required to bridge roof supports. The cost of the support rack can be reduced by proper design and proper building selection. At least one solar manufacturer has addressed this problem and is producing its own collector support rack.

The cost of the storage unit is unlikely to be significantly reduced. Storage tanks are manufactured for numerous industries, and the price is accordingly stable. There are, however, many installations where a storage unit is not required (see Sections 2.1, 3.1 and 3.2).

Design fees are likely to decrease slightly as designers become more familiar with solar heating systems. In addition, design fees are generally a fixed percentage of the system cost; if the system cost goes down, then design fees will decrease.

Based on the above analysis, the cost of solar heating systems will not increase as fast as the general inflation rate. It is, however, unlikely that there will be a dramatic cost reduction in the near future.

Of more importance in the determination of future solar heating system economics is the future cost of conventional fuels. There are many parts of Canada (e.g., the Maritimes), where the cost of conventional fuels can be expected to increase at a rate much greater than the general inflation rate. These areas will probably experience fuel prices that will reduce solar heating system payback periods to under 10 years.

The solar products available on the international scene are similar to those available in Canada, with one major exception: high temperature collectors. The design, performance, and reliability of the flat plate collectors manufactured by Canadian companies are comparable with those manufactured in the United States and Europe. As discussed in Section 4.1, there are no Canadian-made high-temperature collectors; this is, however, not the case in other parts of the world.

In general, the manufacture of high-temperature solar collectors is dominated by the large multinational companies. The high research and development costs and difficult technical problems make it hard for small companies to develop products. A list of high-temperature collector manufacturers includes Owens-Illinois, General Electric, Philips, Sanyo, General Motors, Lockheed, and Martin Marietta. The products offered by these companies range from evacuated tube collectors to solar tracking heliostats for solar power tower systems. There are many industrial installations of high-temperature collectors, especially in the south-western U.S. Examples include can-washing for Campbell Soup Co. in Sacramento, California (parabolic trough), concrete block curing for York Building Products in Harrisburg, Pennsylvania (linear concentrator) and textile dyeing for Rigel Textile Corporation in La France, South Carolina (evacuated tube).

The economics of solar heating appear more attractive outside Canada because of higher levels of solar radiation, higher conventional fuel costs, and lower material costs in other countries.

The solar radiation on a surface tilted to receive the maximum solar radiation varies considerably around the world. Clear climates, such as that found in New Mexico, receive over 60% more solar radiation than moderately cloudy locations such as Toronto and almost twice the amount that cloudy locations such as Vancouver receive. This results in much higher equipment performance and a shorter system payback period.

The cost of conventional fuels in Canada is considerably below world price. Other countries pay two to five times the Canadian rate for electricity and fuels.

This elevated price has spurred foreign collector sales. World solar sales for 1981 were estimated at four billion dollars (12). Japan, suffering from high electricity prices, has annual domestic sales of 50,000 solar domestic hot water systems alone (13). International governments have recognized the potential of solar heating to reduce dependence on conventional fuel sources. At present, Canada and the United Kingdom are the only industrialized countries not offering financial incentives to purchase solar heating equipment (11).

Canadian solar manufacturers must import many of the components of their solar collectors and heating systems, such as low iron glass, absorber selective surfaces, evacuated tubes, and domestic hot water storage tanks. Solar manufacturers in the major industrialized countries do not have this problem and, as a result, can manufacture and install solar heating systems at a lower price than Canadian firms. A survey of industrial solar installations in the United States and Australia showed installed costs to be approximately 10-20% lower than installed costs incurred in the first year of the Ontario commercial/industrial solar program (14).

The differences in thermal performance, conventional fuel costs, and installed prices show that solar heating, today, is much more economic outside Canada. A solar heating system in Canada might have a simple payback of 30 years, whereas an identical system elsewhere in the world might pay back in under five years. Clearly, Canadian solar manufacturers should seek to exploit foreign markets.

7.1 Conclusions

The warehousing and light industrial building heating loads examined are:

- low-temperature process water heating,
- high-temperature process water heating,
- service hot water heating,
- water-based space heating,
- process or ventilation air heating,
- air-based space heating.

The suitability of solar heating to meet these loads is given in Table 4.

Active solar heating systems are suited to supplying low-temperature process water heating. The solar system would consist of flat plate solar collectors with or without a thermal storage unit.

Solar heating is not able to supply high-temperature process water because there are no Canadian solar collectors capable of producing temperatures above 100°C.

Although the demand for service hot water heating in light industrial buildings is not accurately known, solar heating systems are suitable.

Water-based space heating is not as good an application for solar heating as low-temperature process water or service hot water.

There is a large potential for air-based solar heating systems to supply process and ventilation air heating loads, although the relative roles of heat recovery equipment and solar heating equipment are not clear. To date, air-based solar heating systems have not been widely used in warehouse or light industrial buildings.

Conventional air-based space heating is not as good an application for solar heating as process and ventilation air. A space heating system using thermosyphoning air panels, site built onto a warehouse, is an excellent solar heating application.

Solar Heating Potential Heating Load	Maximum Temperature (°C)	Suitable, Commercially Available Products	Mechanical Viability	Potential Economic Viability	Recommendation Ranking
Low-Temperature Process	<100	Y	Y	Y	2
High-Temperature Process	>100	N	N	N	-
Service Hot Water	50	Y	Y	Y	4
Water-Based Space Heating	80	Y	Y	N	-
Process/Ventilation Air	Variable	Y	Y	Y	3
Air-Based Space Heating	60	Y	Y	N	-
Warehouse Heating (TAP)	30	N	Y	Y	1

TABLE 4: Warehouse and Light Industrial Solar Heating Potential

Y = YES

N = NO

The Canadian solar industry is suffering from low utilization of production capacity because there are more manufacturers than the small domestic market can sustain.

Many new products are being developed to supply light industrial and warehousing heating loads, including high-temperature liquid collectors and low-temperature TAP collectors.

At present Canadian fuel prices, solar heating systems have payback periods in excess of 20 years. This is in contrast to some parts of the world, where payback periods can be under five years.

Short-term economic projections show a shortening of Canadian payback periods due to fuel price increases and in a small part due to reduction in system costs. It is anticipated that several solar applications, such as domestic hot water systems and TAP space heating systems, will have a payback period of under ten years. For industry to accept solar heating systems a payback period of under five years is probably required.

7.2 Recommendations

High-temperature process water, water and air-based space heating are not recommended solar heating applications for warehousing and light industrial buildings. If current high-temperature solar collector development results in a collector costing less than flat plate solar collectors, then high-temperature process water is recommended as a possible solar application.

Low-temperature process water and service hot water supplied by solar heat have potential in light industrial buildings. It is recommended that pre-engineered industrial solar hot water packages be developed. These packages would be pre-designed 20 to 30 collector systems complete with storage and structural support racks.

The concept of using air-based solar collectors to preheat industrial process or ventilation air has potential, although the relative roles of solar

equipment and heat recovery equipment need to be defined.

Space heating of warehouses using thermosyphoning air panels is recommended as one of the best solar heating applications. Installations are required to determine the full potential of these systems using actual installed costs and performance data.

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POOR

QUALITY

ORIGINAL